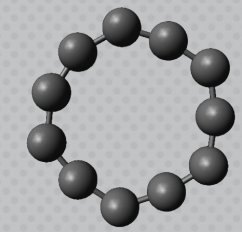
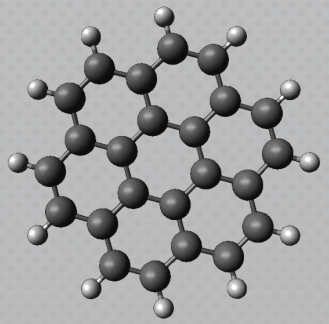


The Aromatic Cosmos: exploring Carbon chemistry in space



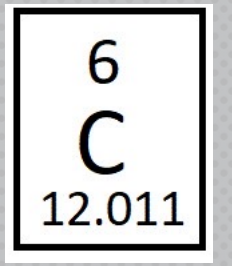
Alessandra Candian
Anton Pannekoek Institute
University of Amsterdam

FIR 2025, 2-5 April 2025, Leiden

DANIII Dutch Astrochemistry Network III

Cosmic Carbon

- 4^{th} most abundant element in the Universe

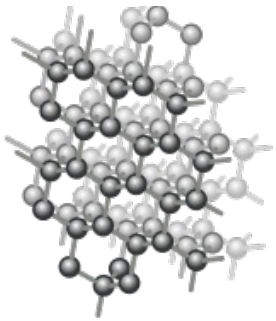


Cosmic Carbon

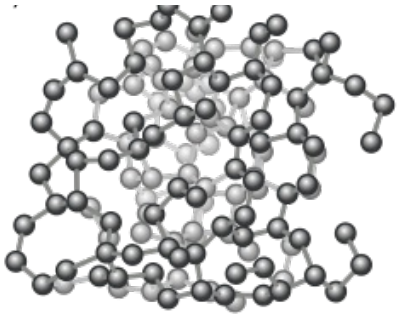
6
C
12.011

- 4th most abundant element in the Universe
- Different "shapes" => building block of life as we know it

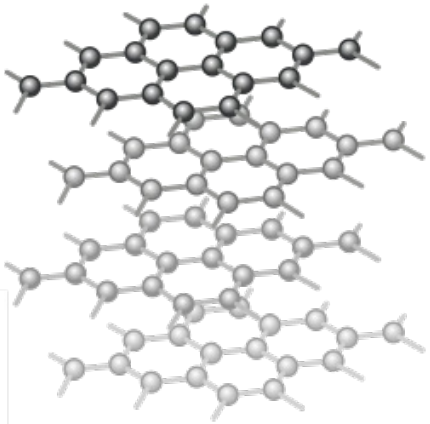
diamond



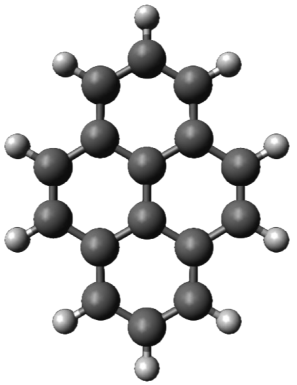
amorphous carbon



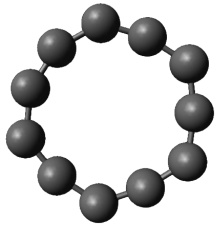
graphite



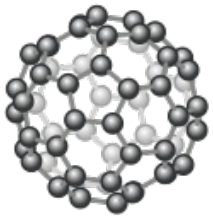
PAHs



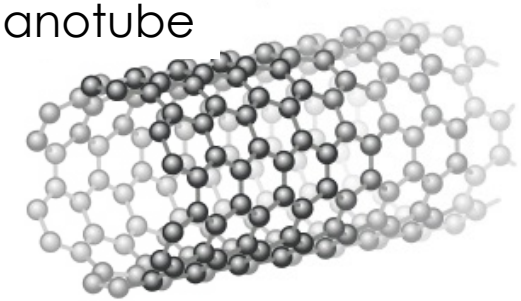
carbon cluster



fullerene

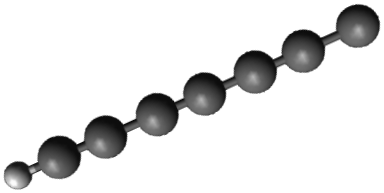


nanotube



C

carbon chain

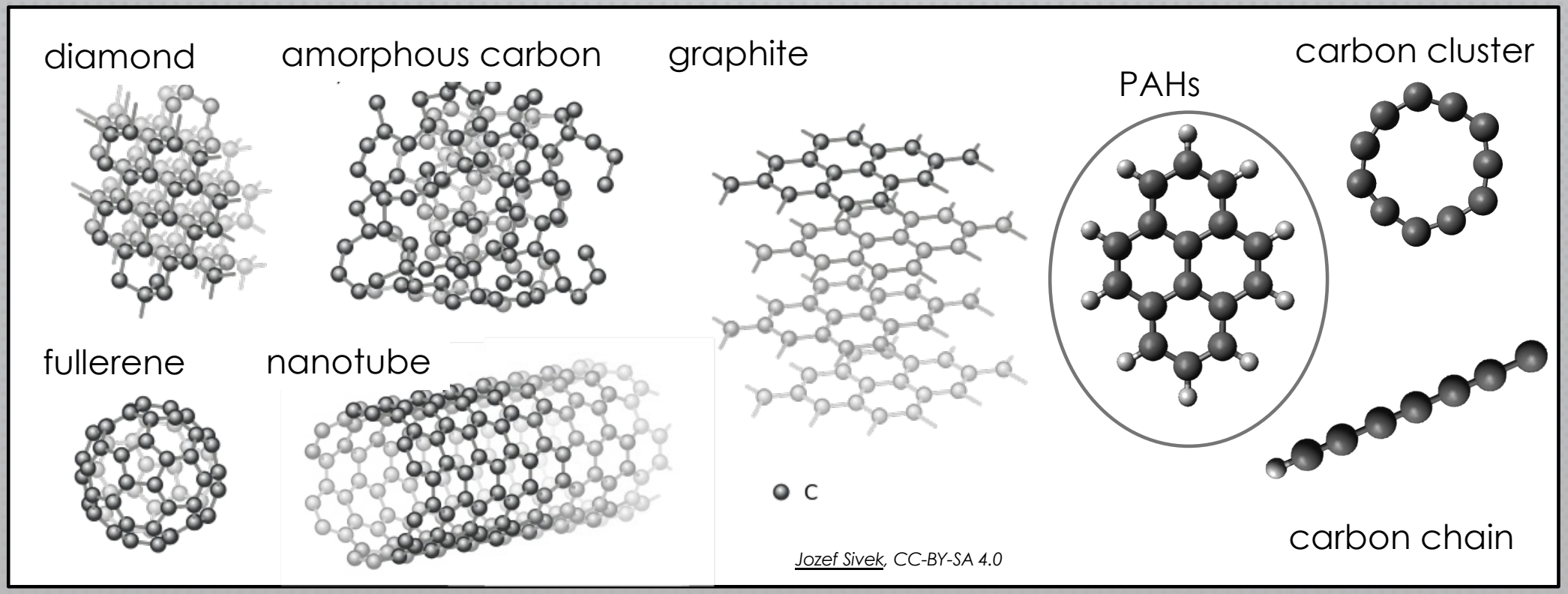


Jozef Sivek, CC-BY-SA 4.0

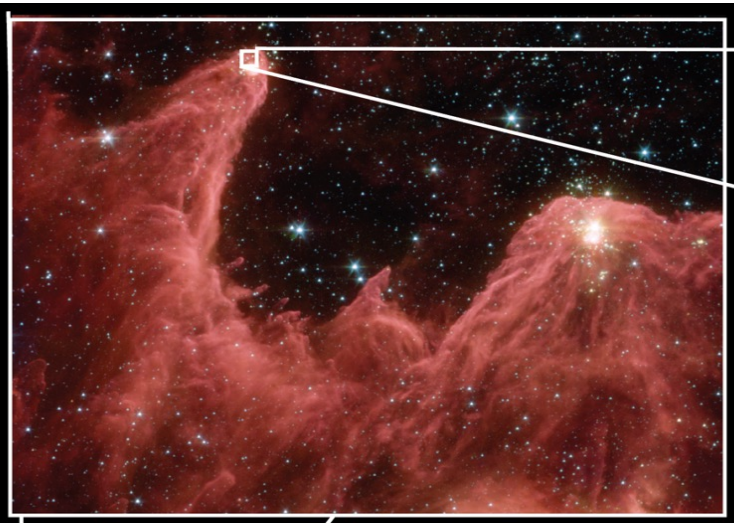
Cosmic Carbon

6
C
12.011

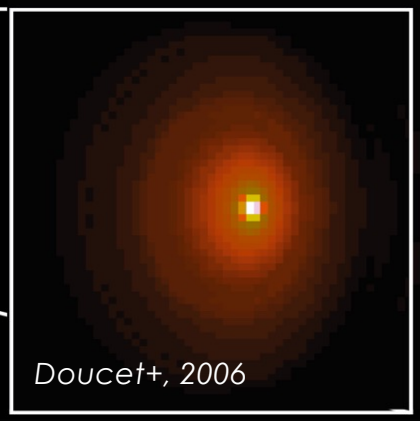
- 4th most abundant element in the Universe
- Different "shapes" => building block of life as we know it



Jozef Sivek, CC-BY-SA 4.0



HD 97048



Star-forming regions

PAHs are STRONG & UBIQUITOUS

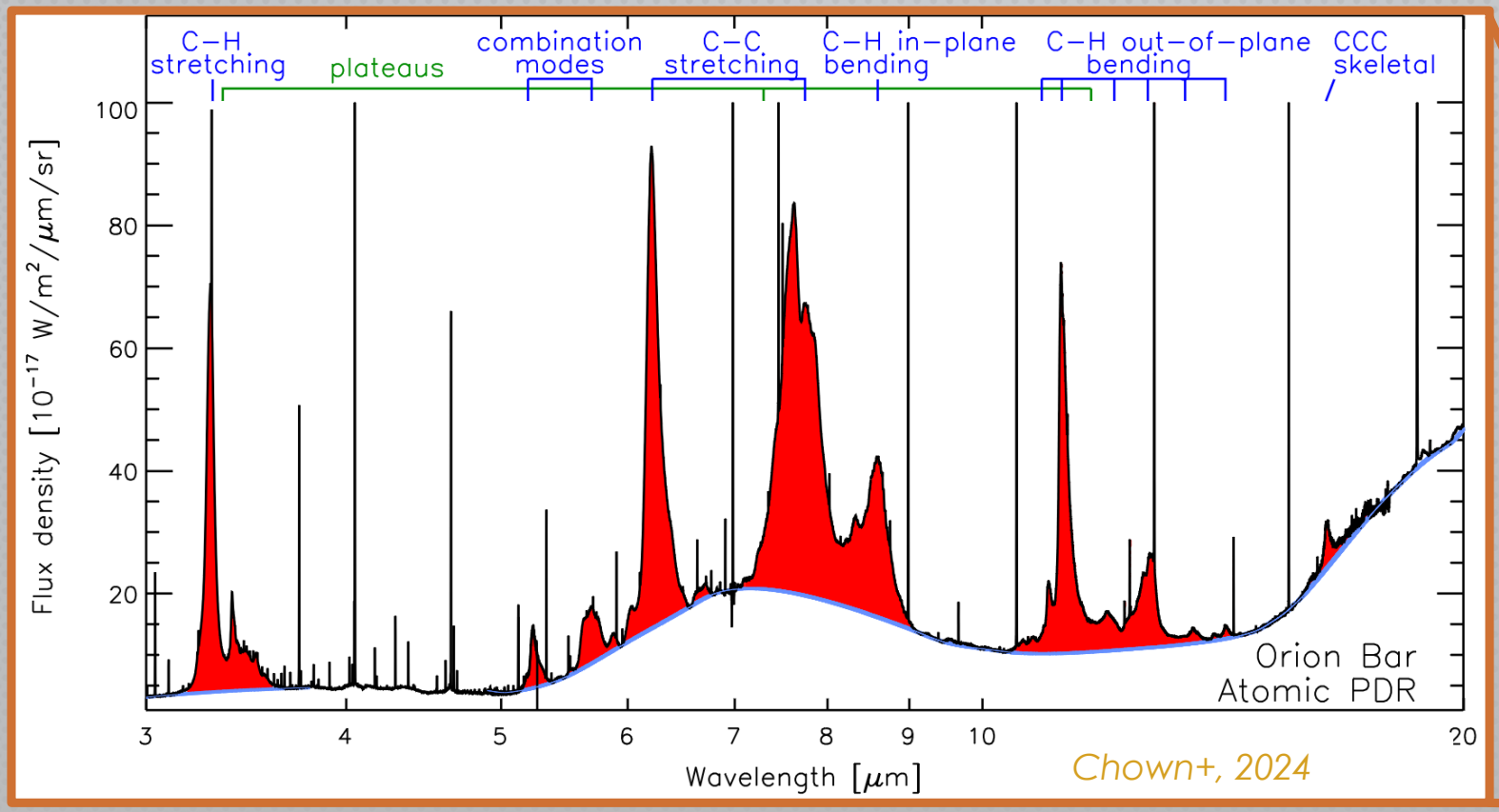
~20% of the IR flux in galaxies & 10% of cosmic Carbon (Tielens 2008)

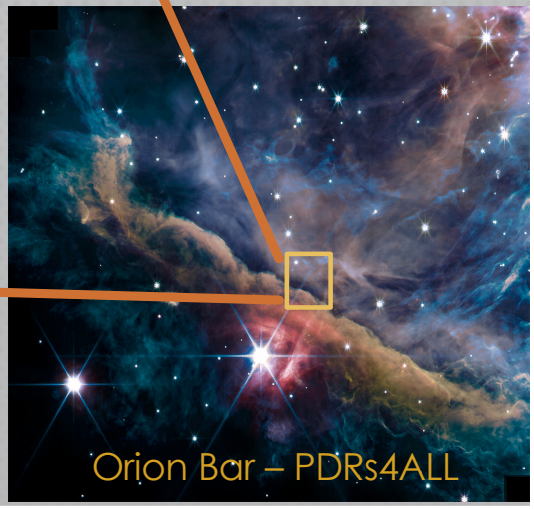
- In galaxies up to z~4 (Rigopoulou+ 2024, Spilker+2023, Chen+, 2024)
- In the Solar system (Lopez-Puertas+, 2013; Vinatier+ 2012; Clemett+2010; Li, 2008)

Perfect TEST molecules to trace the Carbon lifecycle in the ISM

M81

PAHs and Aromatic Infrared Bands





JWST launch gives a new view on PAH emission

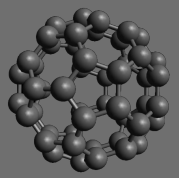
A Population of AstroPAH

Several IR mission and the interdisciplinary work of astronomers, experimentalist and theoreticians put constraints on Astro PAH population

Charge: +/0/-

Size: $N_C > 50$

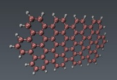
C_{60}



Hetero atoms: D, O

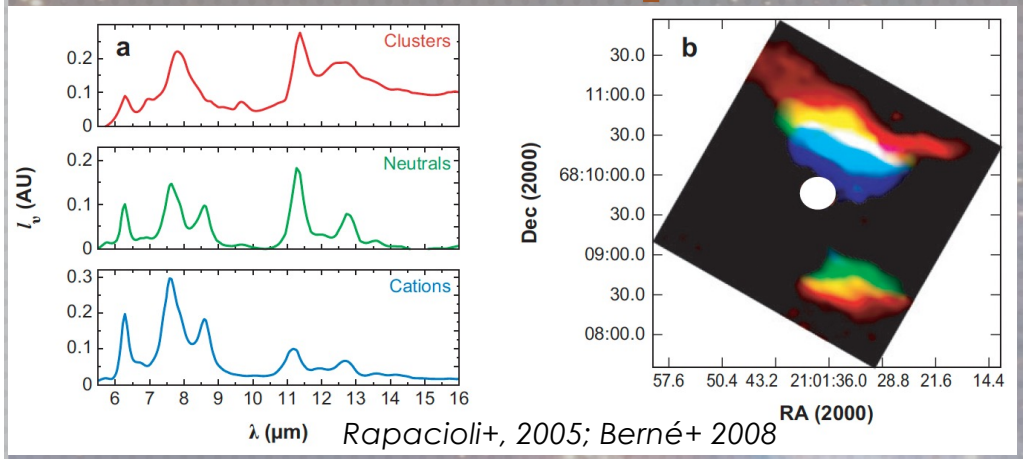
Funct. groups: CH_3, CN

Cosmic PAH portal



PAH IR Spectral Database

A Population of AstroPAH



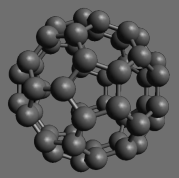
Rapacioli+, 2005; Berné+ 2008

Charge PAHs dominate close ti the central star

Charge: +/0/-

Size: $N_c > 50$

C_{60}



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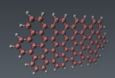
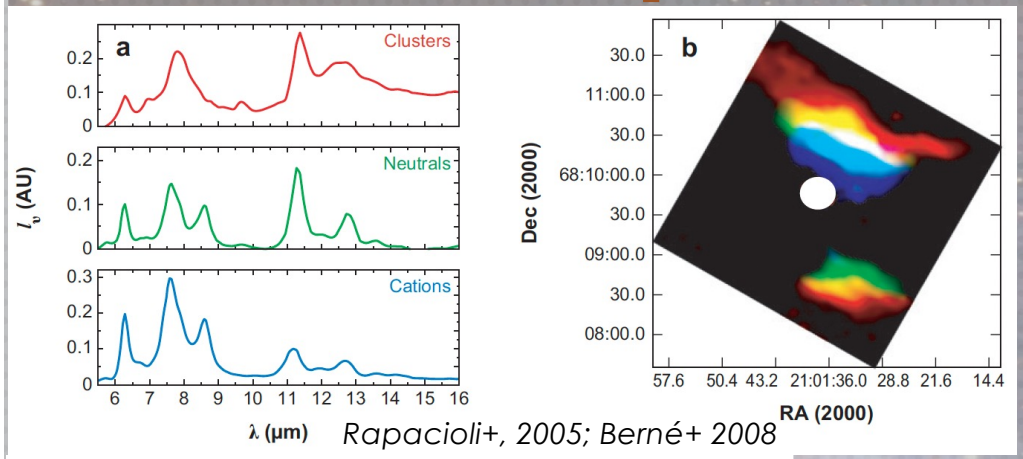


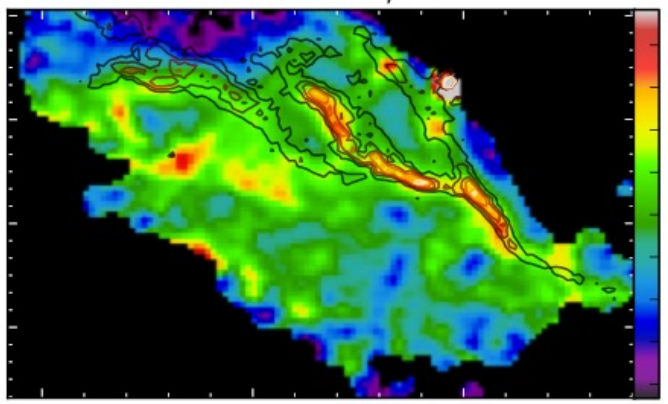
PAH IR Spectral Database

A Population of AstroPAH



Rapacioli+, 2005; Berné+ 2008

3.3 / 11.2 μm *Croiset+, 2016*

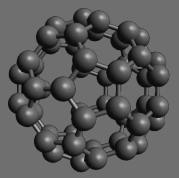


We can trace the PAH size using band ratios.

Charge: +/0/-

Size: $N_C > 50$

C_{60}



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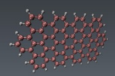
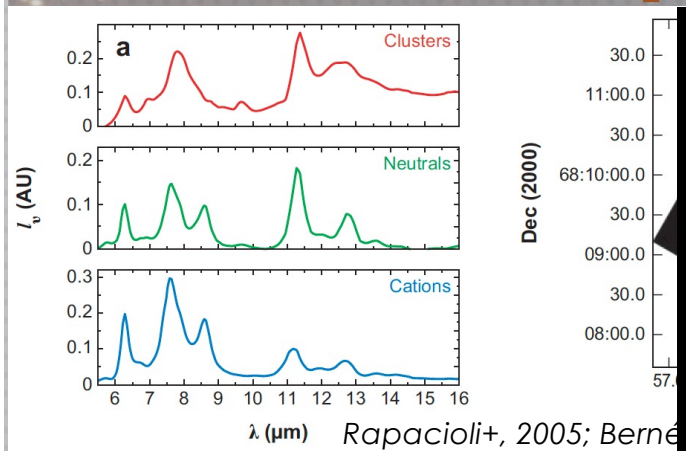
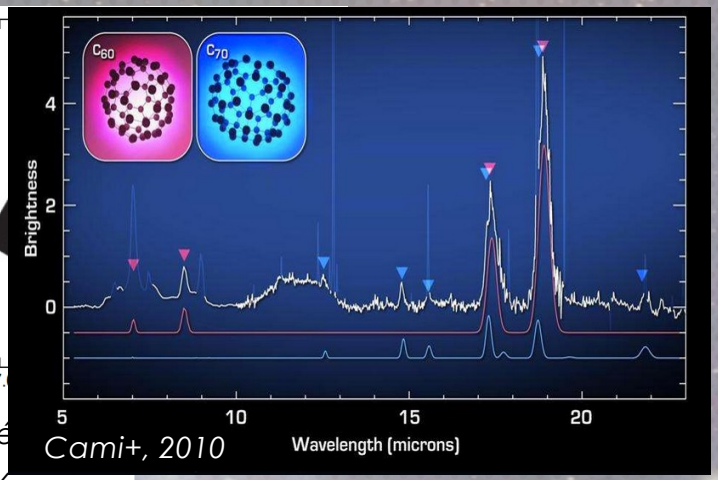


PAH IR Spectral Database

A Population of AstroPAH

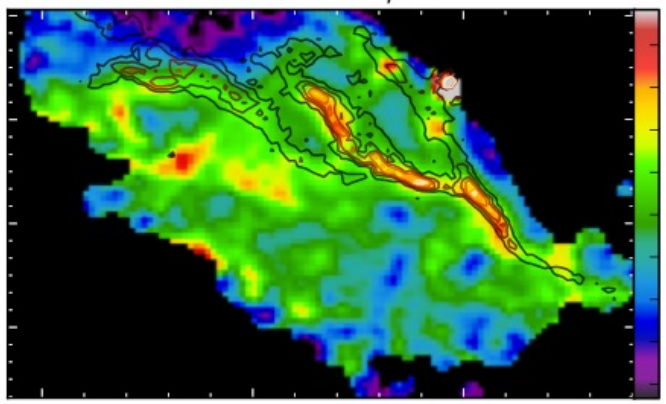


Rapacioli+, 2005; Berné



Cami+, 2010

3.3 / 11.2 μm Croiset+, 2016



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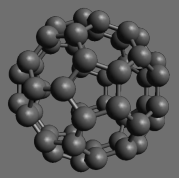
Size: $N_C > 50$

C_{60}



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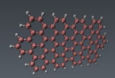
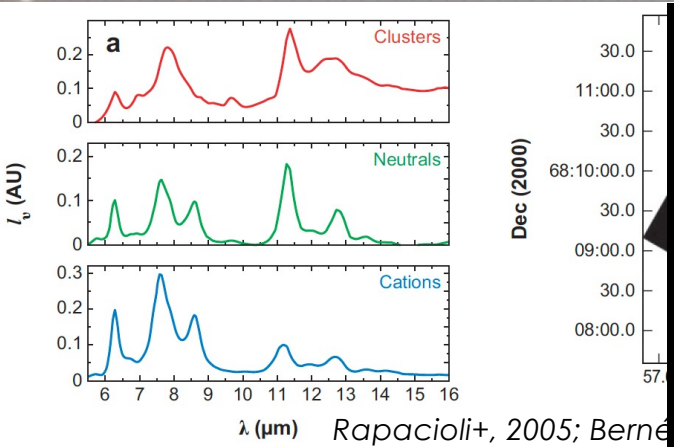
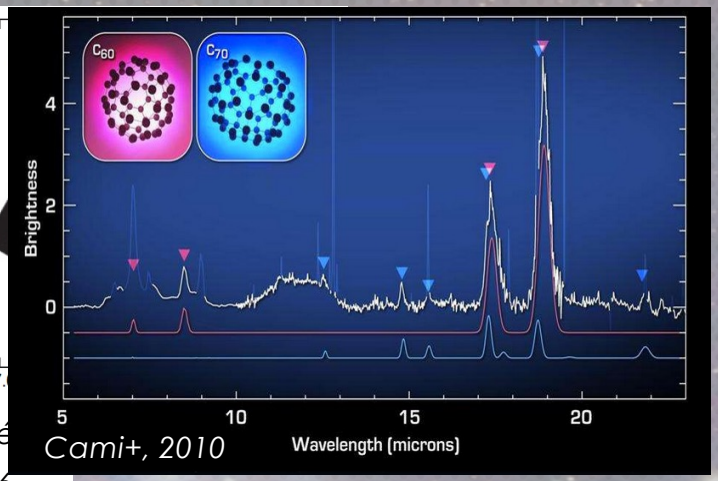


PAH IR Spectral Database

A Population of AstroPAH



Rapacioli+, 2005; Berné



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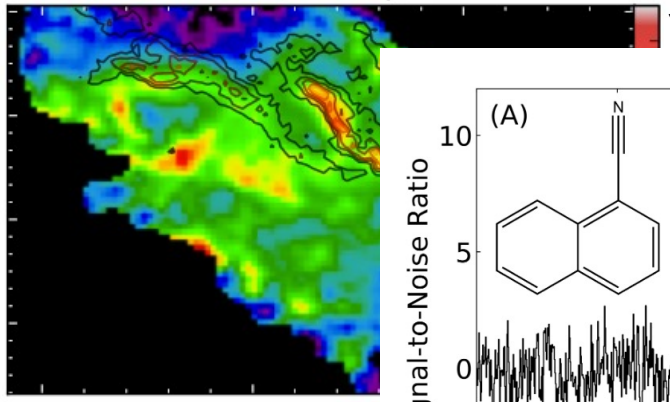
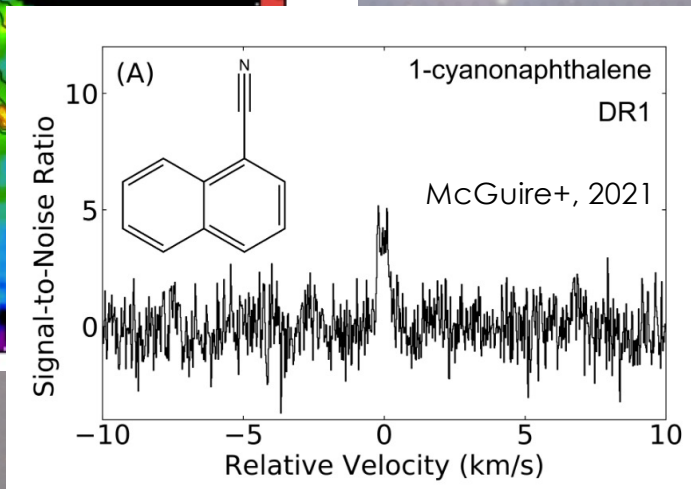


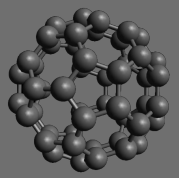


Cernicharo+, 2024
Wenzel+, 2025

Charge: +/0/-

Size: $N_c > 50$

C_{60}



Hetero atoms: D, O

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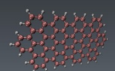
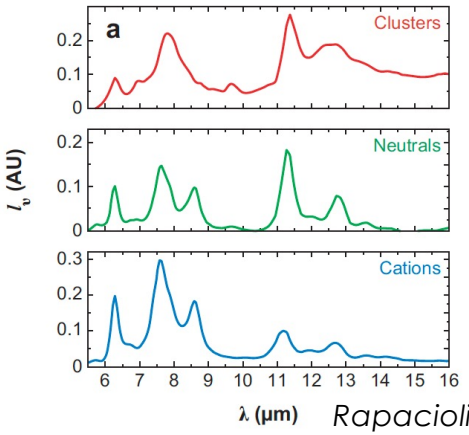
Cosmic PAH portal

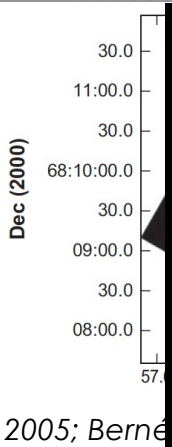


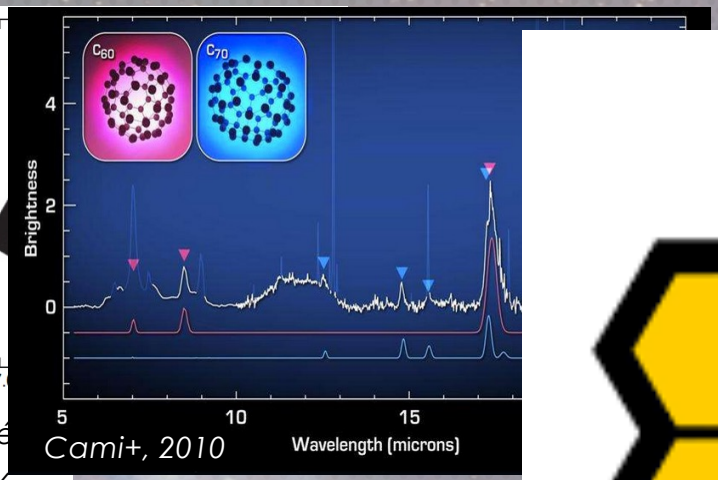
PAH IR Spectral Database

A Population of AstroPAH



Rapacioli+, 2005; Berné





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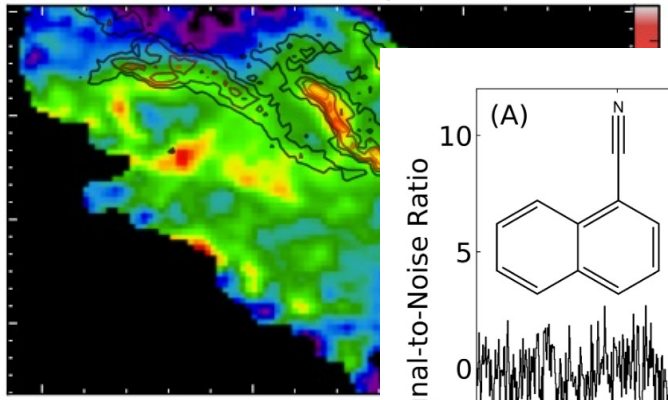
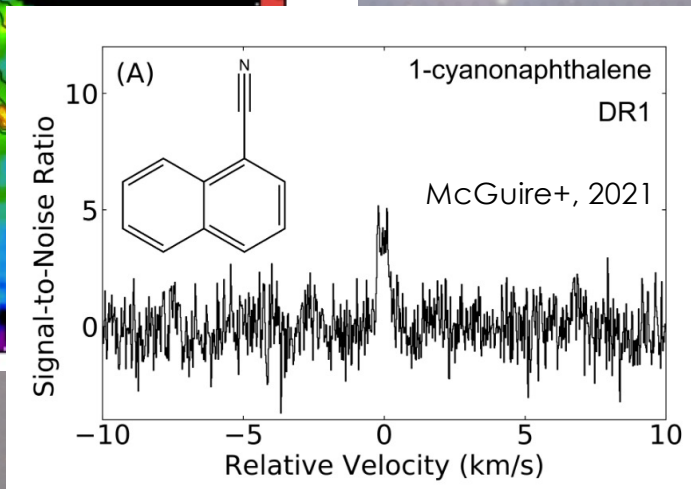
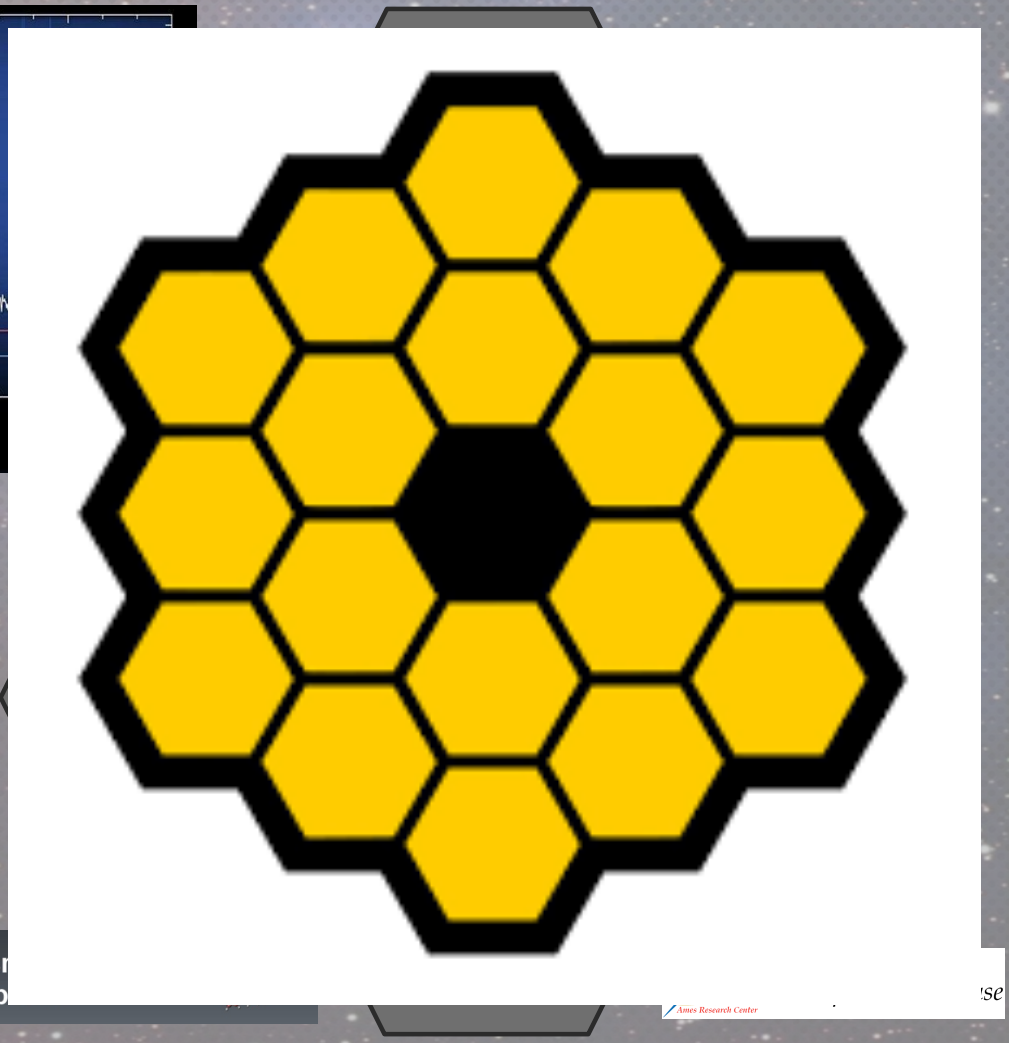




Cernicharo+, 2024
Wenzel+, 2025

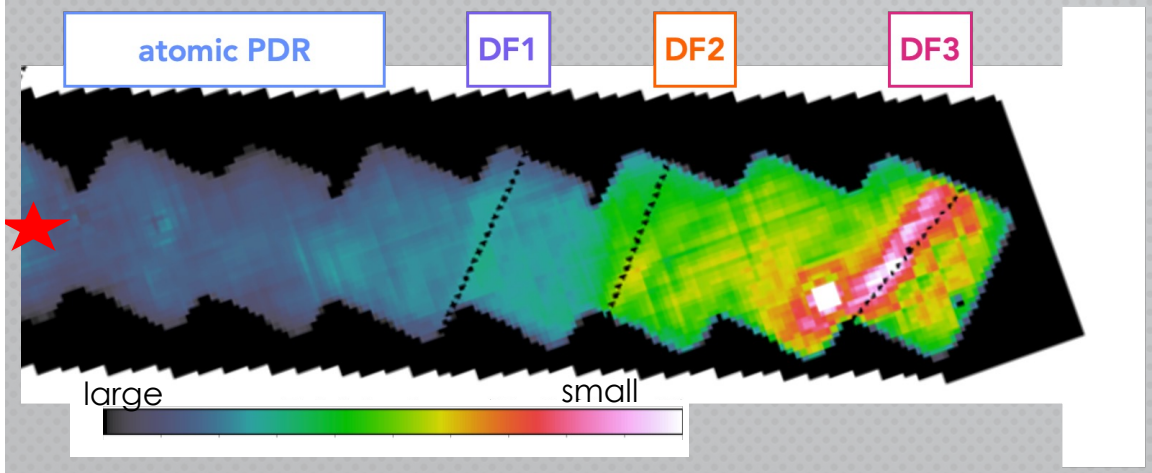


The evolution of AstroPAHs: JWST

PI: Berné, Habart and Peeters

The evolution of AstroPAHs: JWST

PI: Berné, Habart and Peeters



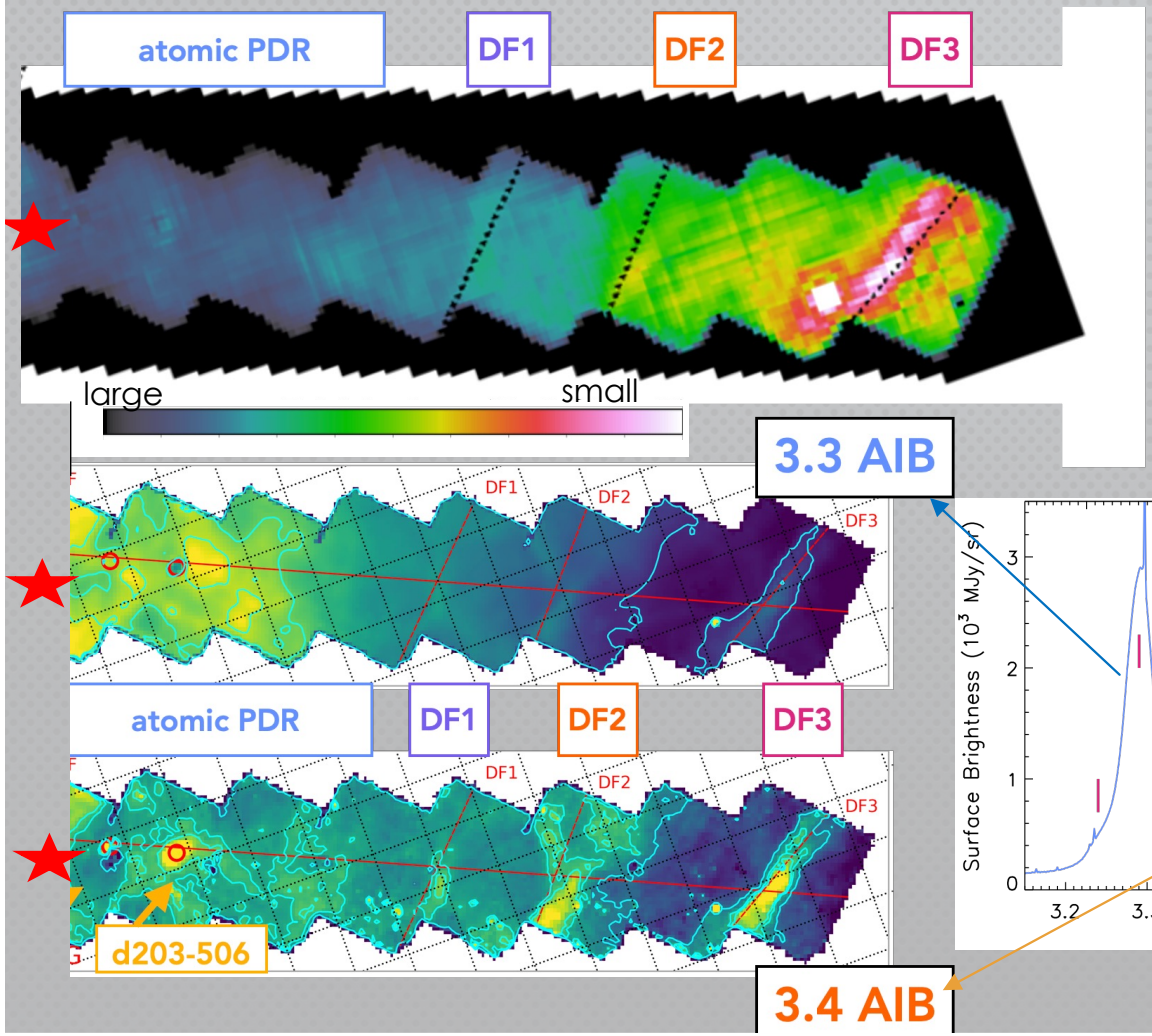
PAH SIZE: 3.3/11.2 ratio

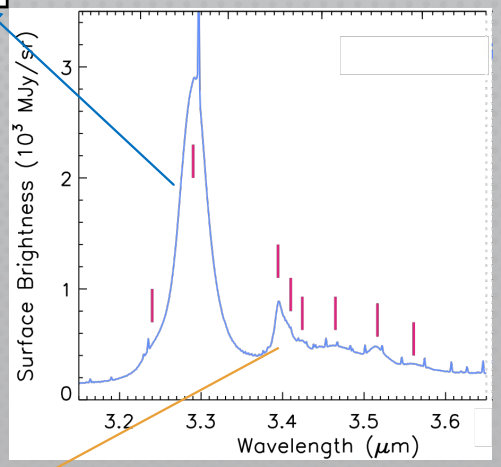
- Larger PAHs closer to the PDR surface
- Smaller PAHs in the more shielded environment

Chown+, 2024; Schefter+, in prep

The evolution of AstroPAHs: JWST

PI: Berné, Habart and Peeters





PAH SIZE: 3.3/11.2 ratio

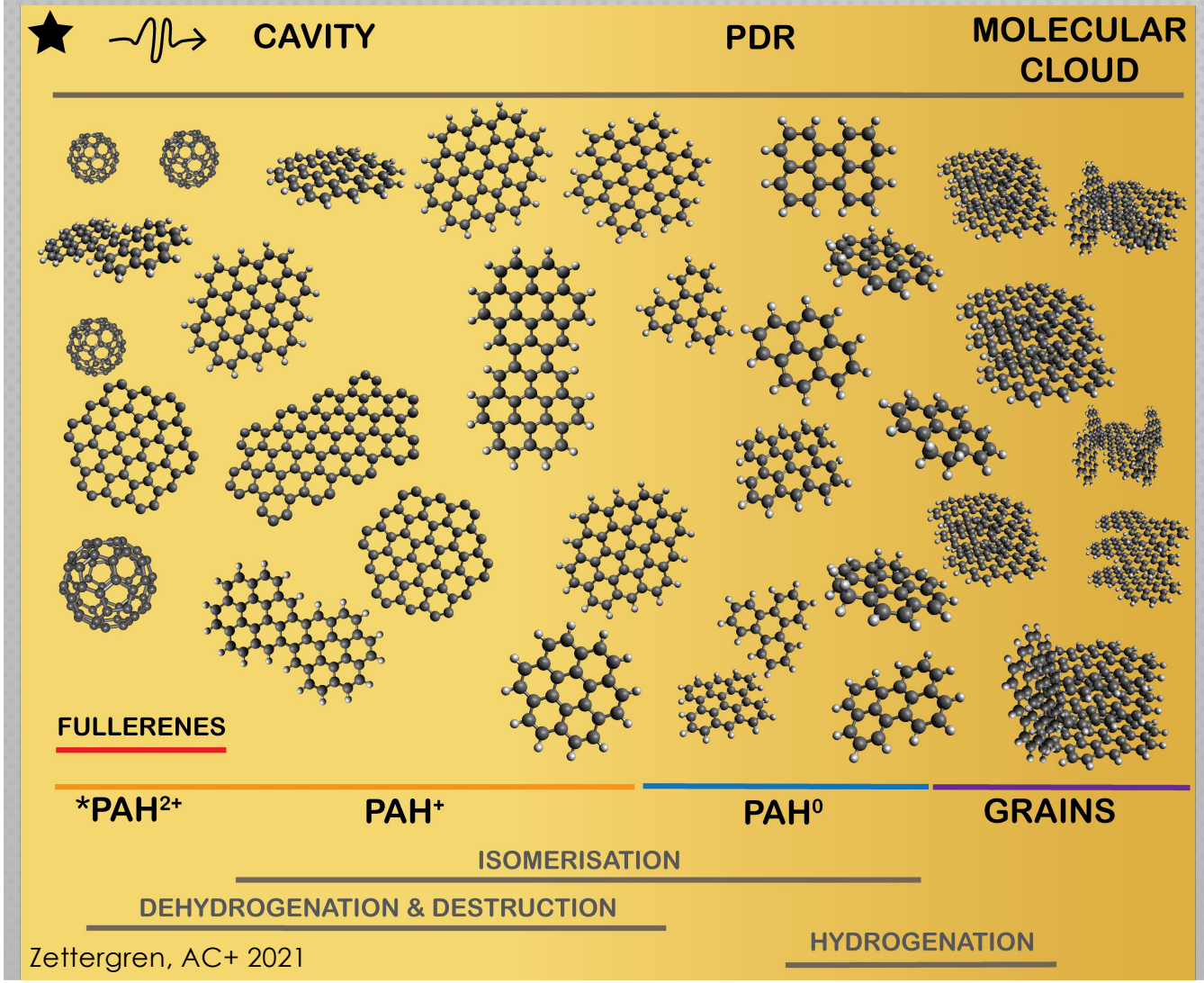
- Larger PAHs closer to the PDR surface
- Smaller PAHs in the more shielded environment

Aliphatic (3.4)/Aromatic (3.3) ratio

- Aliphatic sidegroups destroyed by UV field

Chown+, 2024; Schefter+, in prep

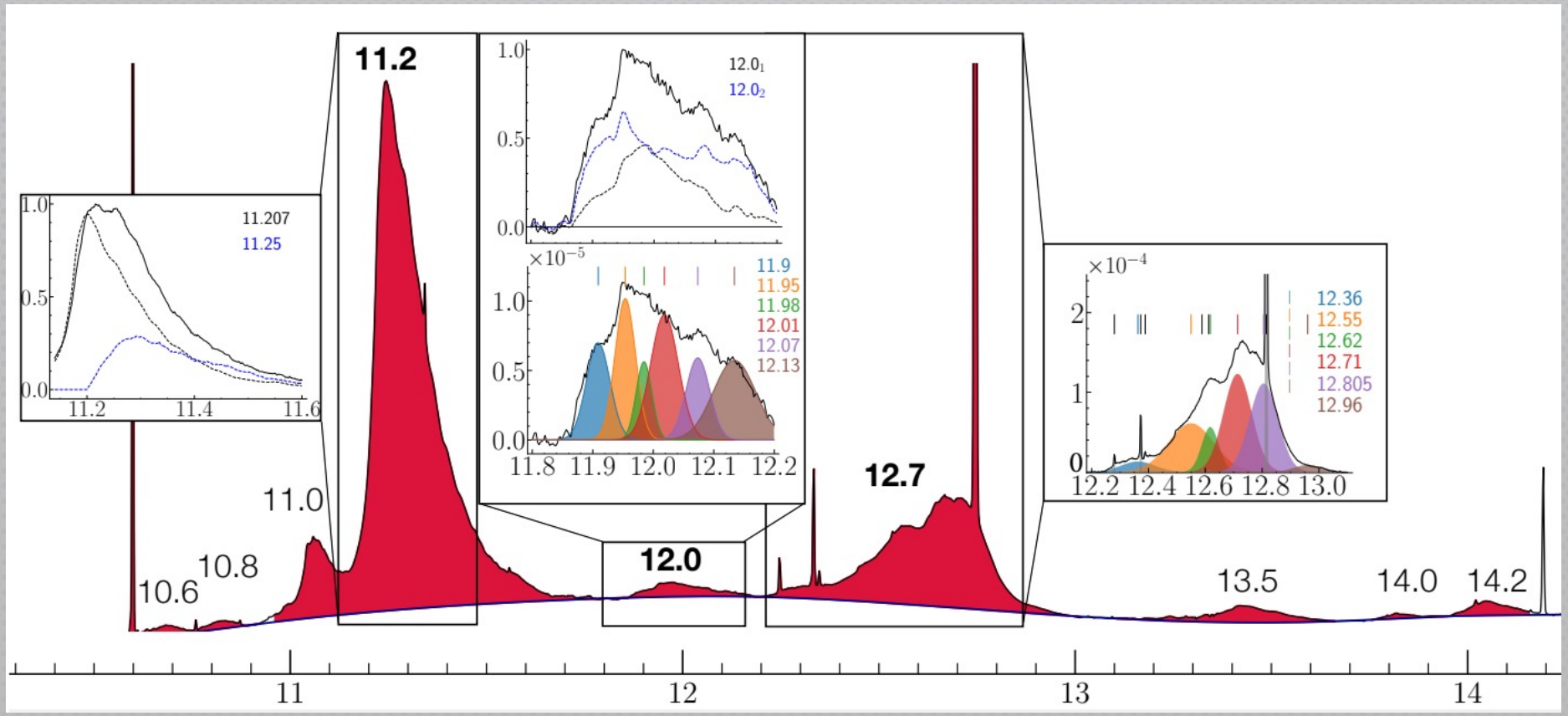
PAH photochemical evolution

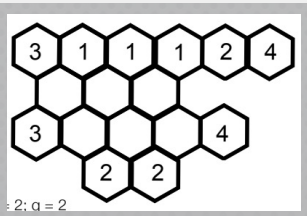


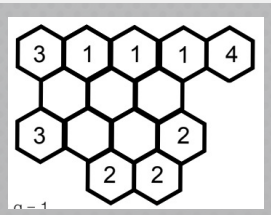
Supported by experiments and modelling

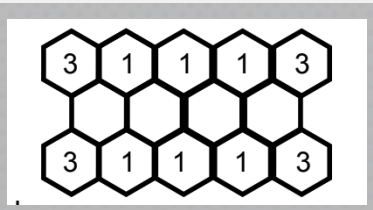
(Berne and Tielens 2010; Montillaud+, 2014, 2016; Castellanos, AC, +, 2018a, b; Andrews, AC, + 2016, Panchagnula, Kamer , AC *et al.*, 2024; Sundararajan, AC *et al.*, 2024)

The shape of AstroPAHs: JWST





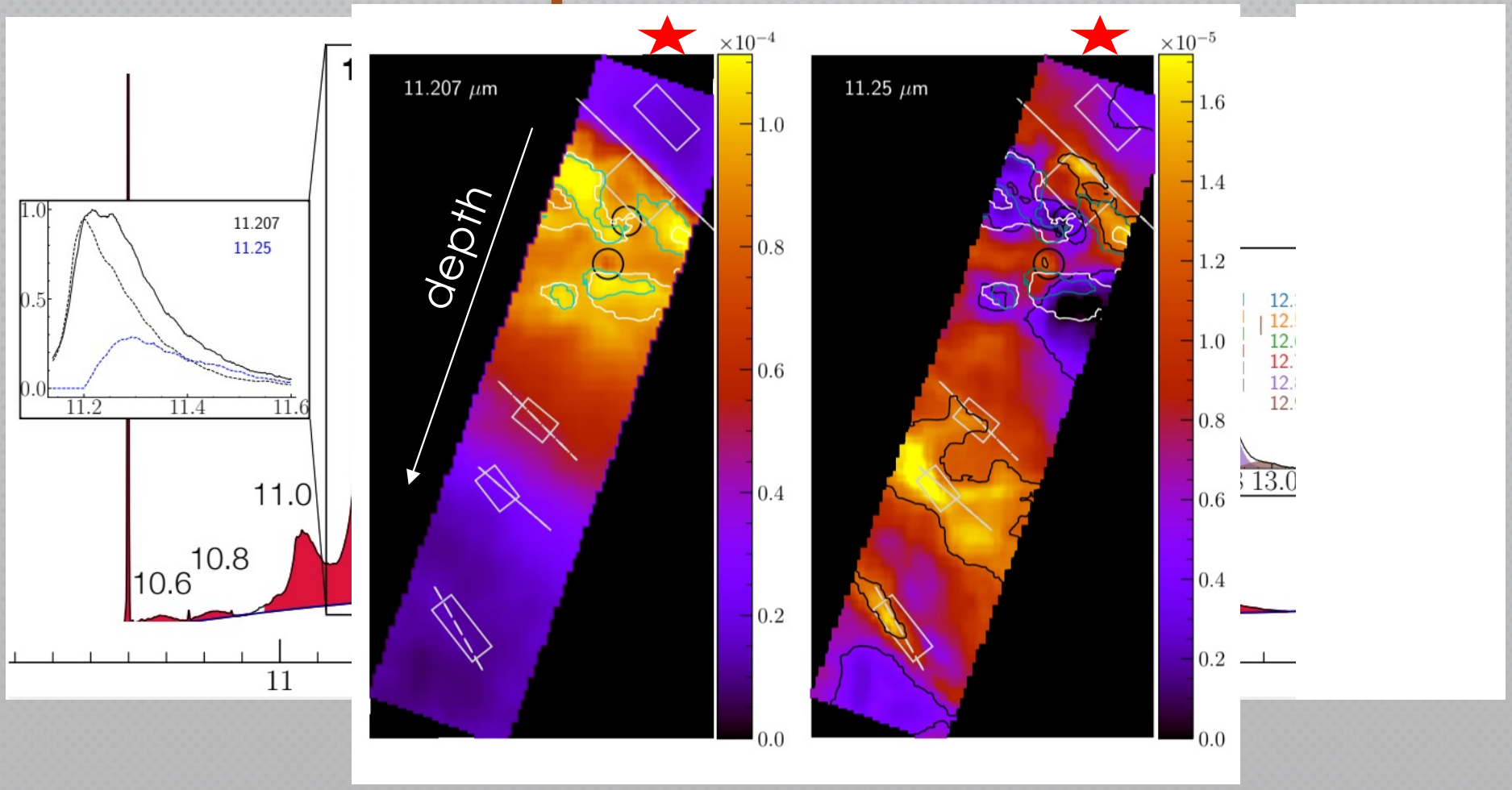




Possible PAH shapes proposed for the Orion Bar

Khan+, 2025

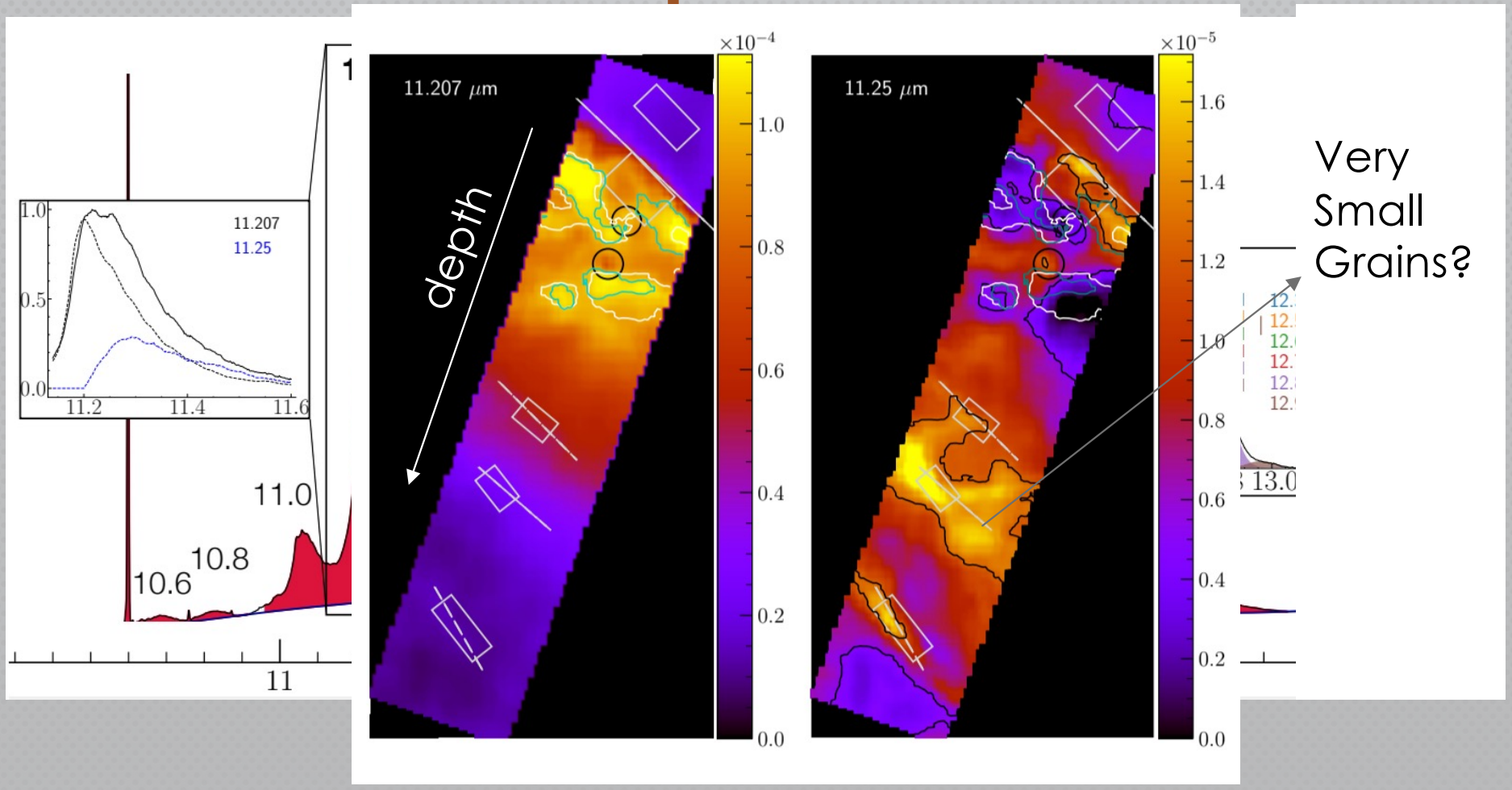
The shape of AstroPAHs: JWST



11.2 μm has 2 components with different spatial distribution

Khan+, 2025

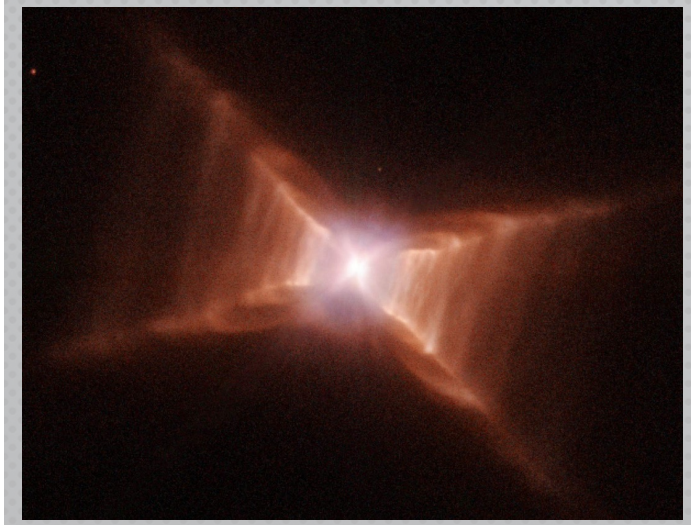
The shape of AstroPAHs

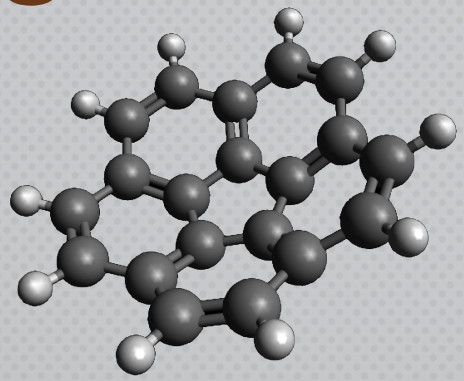


11.2 μm has 2 components with different spatial distribution

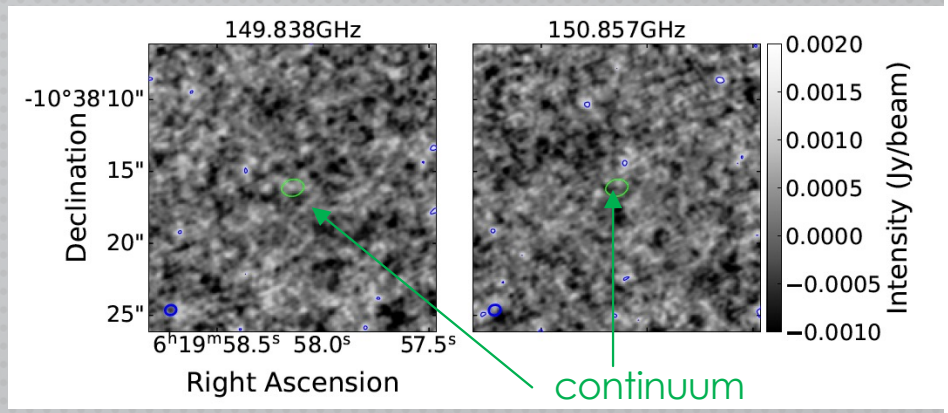
Khan+, 2025

Searching for PAHs with ALMA

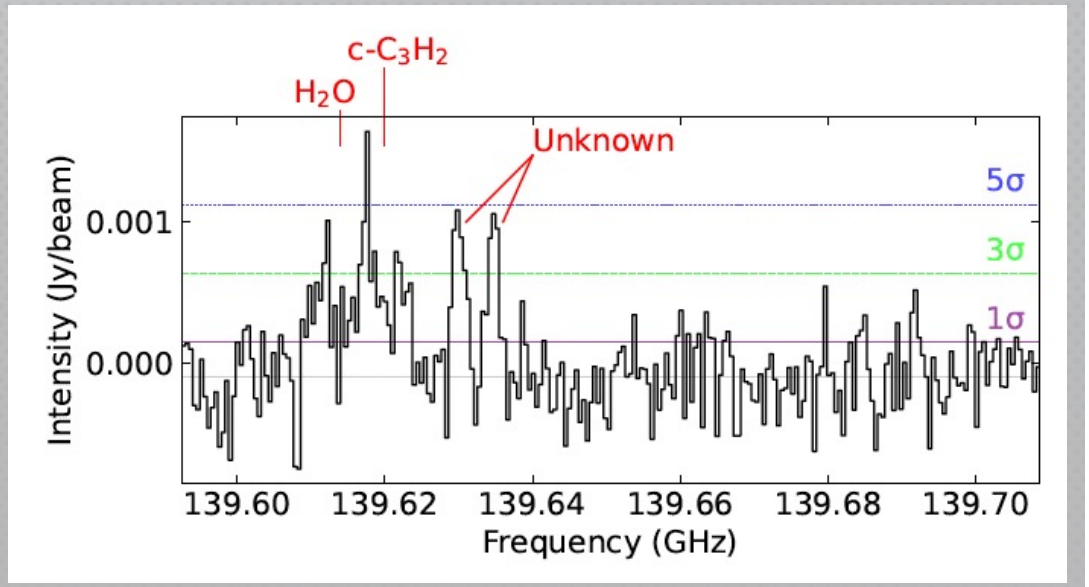




$C_{20}H_{10}$

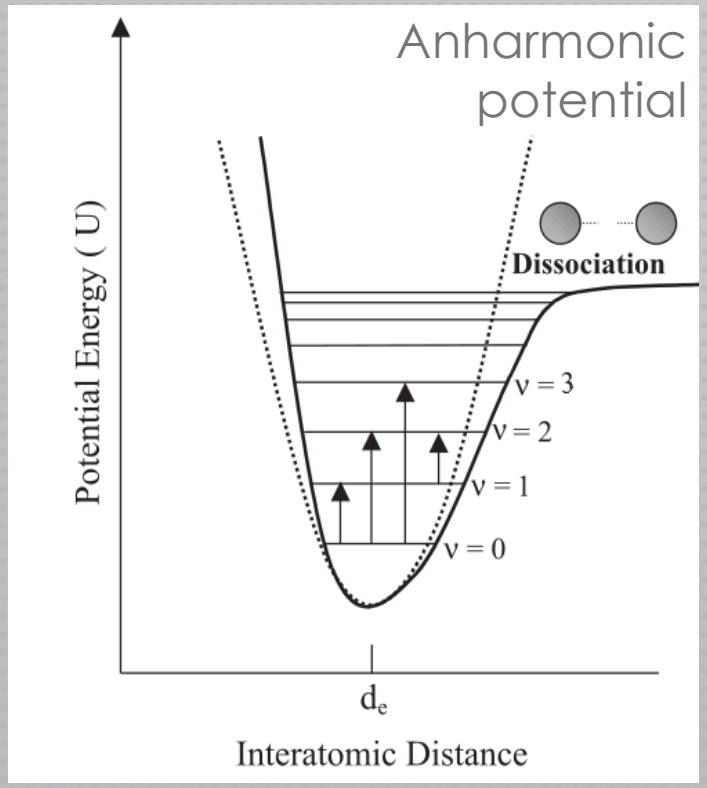


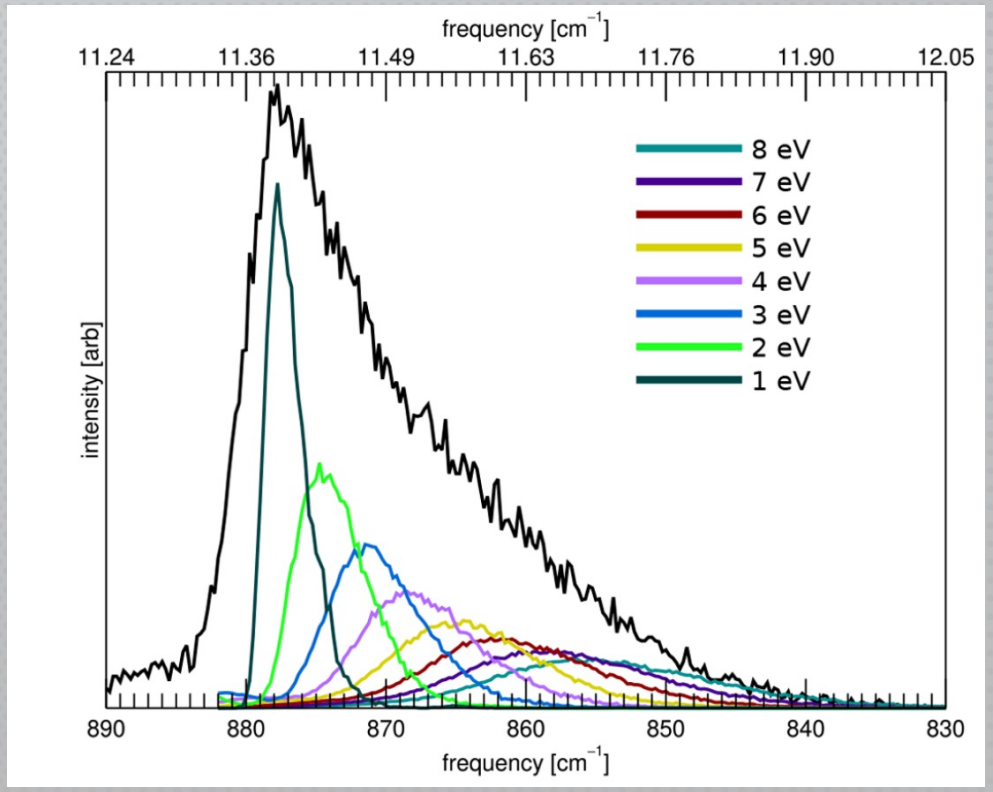
- 9hrs ALMA observations
- Upper limit nC in corannulene: 9×10^{-7}
- Revising formation routes
- Tentative detection of H_2O and c-C_3H_2 : mini-PDR region? (Bujarrabal+, 2023)



Koo, AC, + 2025, submitted

Improving PAH spectral modelling



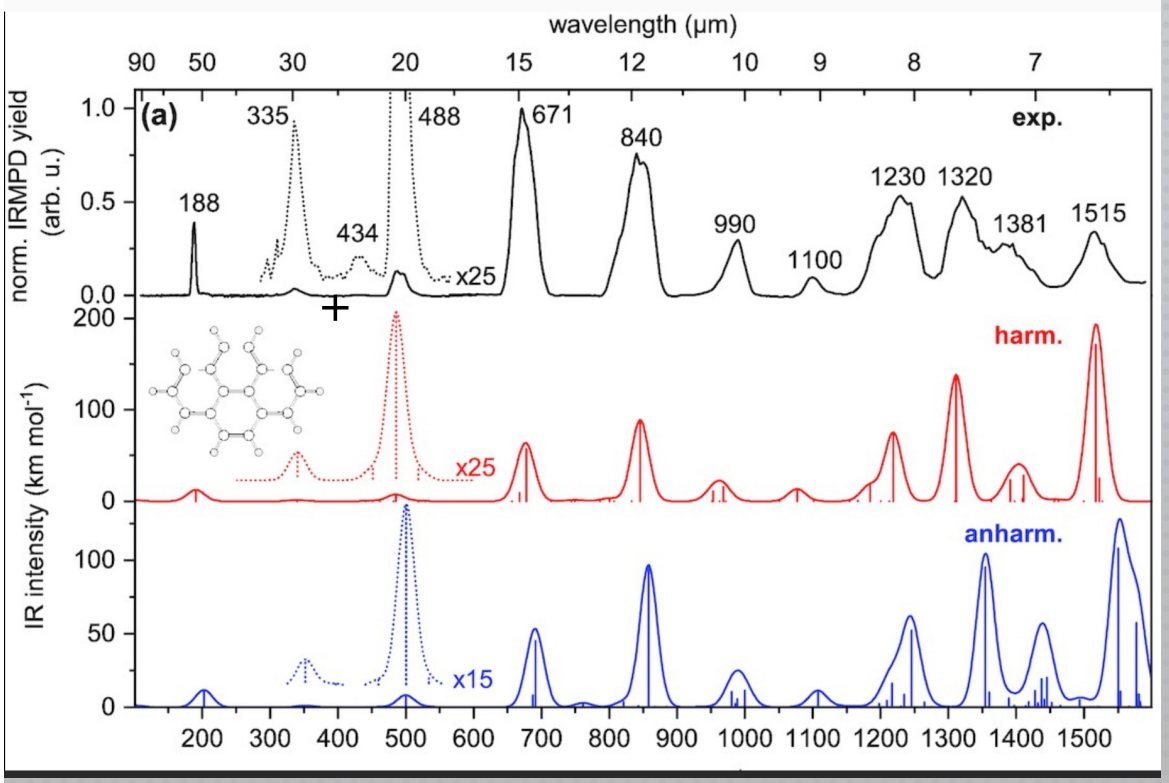


Accurate Quantum Chemistry calculations + benchmark with experiments to obtain "real" PAH emission spectrum

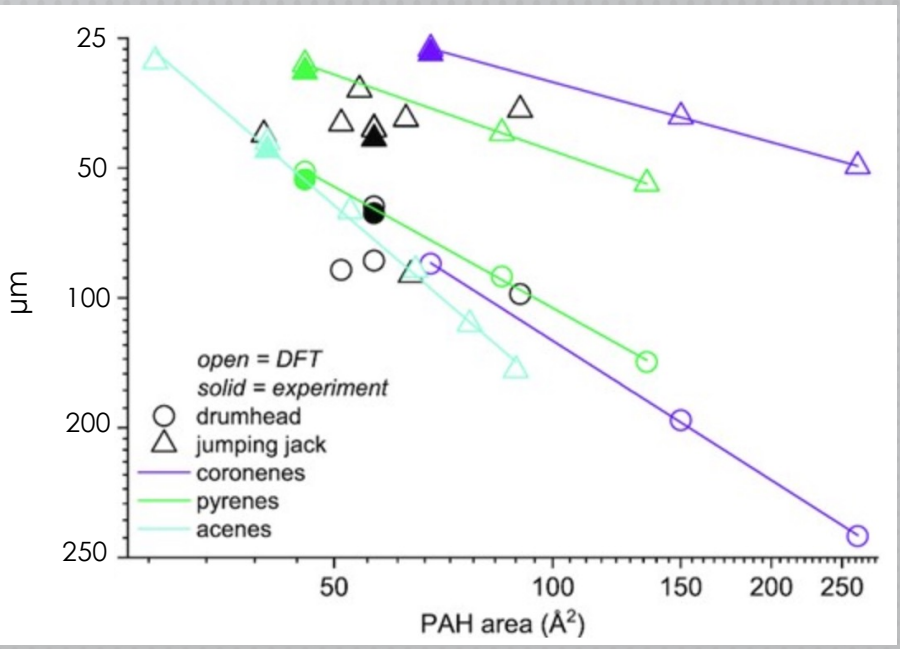
Mackie, AC+ 2021; Peeters+ 2021; Reems, AC + in prep.

PAHs FAR-IR modes and PRIMA

Joblin et al 2011; Wiersma, AC, et al 2022



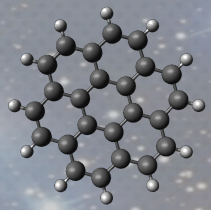
PRIMA\FIRESS



PAHs have intense far-IR very harmonic vibrational modes => FIRESS can "identify" PAHs in irradiated regions because modes are symmetry-dependent

Take home message

- PAHs are fundamental ingredients of the ISM
- JWST allows us to constrain PAH evolution from the ISM to planet-forming regions
- Experiments, Computational chemistry and modelling are fundamental to interpret observations
- FIRESS could identify PAHs in PDRs



DAN Dutch Astrochemistry Network III